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Effects of Inadvertent UH-60 Cockpit Airbag System Deployment on Flight Control

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Two studies were undertaken to assess the effect of inadvertent deployments of a prototype UH-60 cockpit airbag system (CABS) on flight control. In Study One, the effects of inadvertent four-airbag (two forward and two lateral) CABS deployments were investigated; Study Two looked into the effects of inadvertent two-airbag (two forward airbags only) CABS deployments. In both studies, current and qualified UH-60 aviators were recruited to fly 1-hour sorties in an NUH-60 research flight simulator. Simulated inadvertent CABS deployments were introduced into these sorties during six predetermined flight maneuvers. The simulated deployments included uncommanded cyclic and collective motions, obstruction of the forward and lateral viewscreens, obstruction of the instrument panel, and an audible cue (used to crudely mimic airbag deployment noise). Data were collected on the probability of crashing, the time to recover from, or to crash as a result of, each simulated deployment, as well as on the severity of each simulated deployment as perceived by the test subjects, simulator operator, and simulator observer. Results show flight control to be more adversely affected by inadvertent deployment of the four-airbag CABS, particularly during high-speed, low-level flight.

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Table of contents

Page

Appendix

Table of contents (continued)

Page

List of figures

List of tables

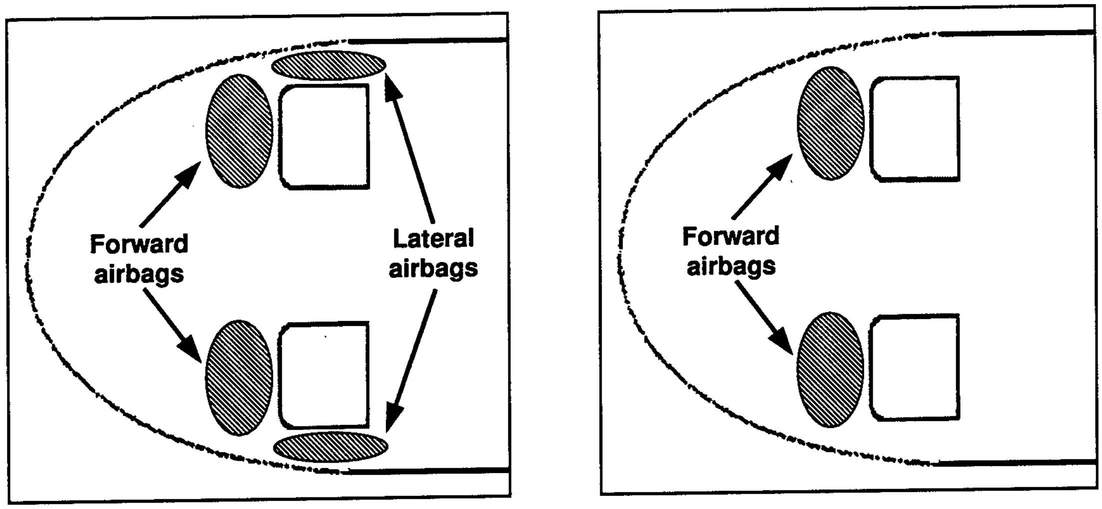
Introduction

Modern Army helicopters incorporate crashworthy features such as energy absorbing landing gear and seats, self-sealing fuel systems, and harness restraints. In addition, aviators are provided an arsenal of personal protective equipment including flight helmets, survival vests, and fire resistant flight suits and gloves. With these advancements has come a reduction in the potential for serious injury in survivable helicopter crashes (Shanahan and Shanahan, 1989; Crowley, 1991).

Even so, helicopter occupants are at high risk of injury during survivable mishaps. Shanahan and Shanahan (1989) have shown that approximately 80 percent of helicopter crash injuries are caused by impacts between the occupants and the aircraft structure. To further reduce the incidence of these impact injuries, the U.S. Army has investigated the possibility of incorporating airbags as a supplemental restraint system in its helicopter fleet. Alem et al. (1992) conducted sled tests simulating severe attack helicopter crashes. Data from these tests showed that an airbag in the cockpit of attack helicopters could reduce most indices of head injury severity by as much as 70 percent. Shanahan, Shannon, and Bruckhart (1993) projected a 23 percent reduction in injuries and a 50 percent reduction in fatalities during survivable helicopter mishaps through the use of airbags. Based largely on these U.S. Army Aeromedical Research Laboratory (USAARL) studies, development of a Cockpit Airbag System (CABS) for retrofit into existing aircraft was begun in the mid-1990s.

The use of any airbag restraint system brings with it the risk of inadvertent deployment, and several aspects of inadvertent deployment present a risk to flight control. First, high-speed video taken of live UH-60 prototype airbag deployments in a UH-60 aircraft have shown the forward and lateral airbags to move the flight controls (either through direct or indirect interaction with the cyclic and collective). Second, when fully inflated, the prototype airbags obstruct the aviator's view of the instruments, as well as out the aircraft's windows. Third, by definition, inadvertent deployments can happen at any time, including while occupants are out of the ideal body posture, thereby increasing the risk of physical injury to the aircrew (Brozoski et al., in press and McEntire, in press). Any combination of these circumstances may prohibit the flight crew from maintaining effective control of the aircraft.

This report describes two studies that were undertaken to assess whether aviators could maintain aircraft control in the event of an inadvertent CABS deployment. The first study was designed to evaluate Army aviators' ability to manage the inadvertent deployment of a four-airbag CABS (two forward and two lateral airbags, figure 1a). In the second, the aviators were subjected to inadvertent deployments of a two-airbag CABS (two forward airbags, figure 1b). For both studies, the effects of inadvertent CABS deployments (e.g., uncommanded flight control motions and obstruction of the aviator's views of the instruments and outside the windows) were simulated in USAARL's NUH-60 research flight simulator. While the possibility of aviator incapacitation due to airbag-induced injury is certainly a threat to flight control, it was not addressed for human subject safety reasons. To evaluate the effects of these events on aircraft flight control, probability of crash, time to recover, and perceived difficulty were chosen as metrics.



(a) Four-airbag CABS (b) Two-airbag CABS

Figure 1. Diagrams of the two- and four-airbag CABS configurations. Airbag locations are shown relative to cockpit seats.

Study One: Four-airbag CABS

Method

Apparatus

All sorties were flown in the NUH-60 research flight simulator located at USAARL. The NUH-60 simulator is a Black Hawk training simulator that has been modified for research purposes. The simulator is equipped with a multi-channel data acquisition system capable of collecting flight performance data (heading, altitude, etc.), as well as subject physiological data (heart rate, core temperature, etc.). In addition, low-light video cameras are located throughout the cockpit for real-time subject monitoring and the creation of videotape records of each sortie.

The software that controls the motion base of the NUH-60 simulator was modified to allow the effects of a deploying airbag to be simulated (Raytheon Systems Company, 1999). High-speed video recordings of live airbag deployments in the cockpit of a CABS-equipped UH-60 aircraft assigned to the U.S. Army Aviation Technical Test Center (USAATTC) have shown these effects to include:

- movement of the cyclic and collective by direct and indirect contact with the deploying airbags,

- temporary obstruction of the aviator's view out the forward windscreen and lateral windows, and

- temporary obstruction of the aviator's view of the instrument panel by the deployed forward airbag.

A further effect, which is expected in actual CABS deployments, is the startle to the occupant caused by the sudden change in visual field, the noise, and possible flash that accompany a deployment.

The software modification allowed a simulation of these effects to be introduced at any time during the sortie. To simulate airbag/flight control interaction, the software change allowed the investigator to specify representative flight control deflections, (e.g., a 1-inch forward cyclic displacement). The flight control deflections were reproduced in the physical flight control. (The flight control motion provided a tactile cue to the pilot, but motions occurred slowly enough as to avoid any risk of injury to the hand holding the control.) The simulator motion base responded normally to these flight control deflections (e.g., pitching the simulator forward if a forward cyclic motion was specified). Blacking out the instrument panel lighting simulated the temporary obstruction of the instrument panel. To simulate the temporary obstruction of the aviator's view outside the aircraft, the viewscreens (forward and lateral) were turned white. The software modification allowed the investigator to specify how long the viewscreens remained white and instrument panel lights were blacked out. An aural cue was also included to crudely mimic the sound associated with airbag deployment.

Rationale for the airbag deployment simulation

The magnitude or duration of each component of the simulated airbag deployment is shown in table 1. The values shown in table 1 were obtained from analysis of high-speed video or airbag performance specifications. Video footage showed the forward airbag making contact with the top of the cyclic and dragging it forward (in the direction of the aircraft's nose) approximately 1 inch during inflation. Video records also showed interaction between the right side lateral airbag and the right arm of an anthropomorphic test device (ATD) seated in the right crewseat. This interaction forced the ATD's right arm, and consequently the cyclic, forward and to the left, resulting in the 1-inch leftward cyclic motion. Similarly, the left side lateral airbag interacted with the left arm of an ATD seated in the left crewseat, causing a downward collective displacement of approximately 2 inches.

Table 1.
Components of simulated inadvertent deployment of the four-airbag CABS.

Component	**Event**	**Magnitude/duration**
Cyclic motion	Forward Leftward	1 in. 1 in.
Collective motion	Downward	2 in.
Windscreen views	Forward display turns white Lateral display turns white	3 sec. 3 sec.
Instrument view	Panel lights black out	5 sec.
Deployment noise	Aural cue	--

The UH-60 CABS design specification calls for 3 seconds of impact protection; it was assumed that the forward and lateral airbags would remain inflated and block the aviator's view outside the aircraft for the entire time. Instrument panel lighting was blacked out for 5 seconds simulating an airbag deflating and covering the instrument panel. It was assumed that the instrument panel would be completely blocked by the forward airbag for the entire 3 seconds; an additional 2 seconds were added as an estimate of the time necessary to remove the deflating airbag from the instrument panel. Finally, an audible cue was introduced to crudely simulate the sound of a deploying airbag.

Experimental design

Subjects

Ten subjects were planned for this study. Each subject was a qualified UH-60 Black Hawk aviator who was current on the aircraft at the time of participation. Potential subjects were screened on the basis of whether they had a valid Department of the Army Form 4186 ("up slip") stating that the aviator was fit for simulator flight. Any subject not possessing a valid "up slip" was excluded from participation. No anthropometric requirements, e.g., minimum sitting height, were imposed on potential subjects. Subject anthropometry was not considered critical in this study, as there was no intention to identify any occupant/airbag interaction.

Briefing

The subjects meeting the selection criteria were briefed formally on the nature of their participation in the study. The subjects were informed that simulations of inadvertent airbag deployments would be introduced during a 1-hour sortie (emphasis was placed on the fact that no actual airbags would be deployed; thereby, eliminating the risk of airbag-induced injury). The subjects were not told how many deployments would be introduced, nor when during the sortie the deployments would occur. Also, the subjects were not informed as to the nature of the simulated inadvertent deployment (e.g., loss of instruments or uncommanded flight control motions). The subjects were instructed that after each simulated deployment they were to regain control of the aircraft and return as quickly as possible to predeployment flight parameters.

Sortie

Each subject flew a 1-hour mission in USAARL's NUH-60 research flight simulator. The flight profile (figure 2) was flown under visual meteorological conditions (VMC) with 5 miles visibility. The sorties were flown as single-pilot missions with the subjects seated in the right crewseat. During the flight, six simulated inadvertent CABS deployments (represented by X's in figure 2) were introduced into the flight profile during specific maneuvers. Figure 2 shows the sequence of deployments beginning with straight and level (S&L) flight and continuing in a counterclockwise direction to nap-of-the-earth (NOE) flight. The sequence of simulated deployments remained constant for all subjects. A complete description of the flight profile is provided in the Appendix.

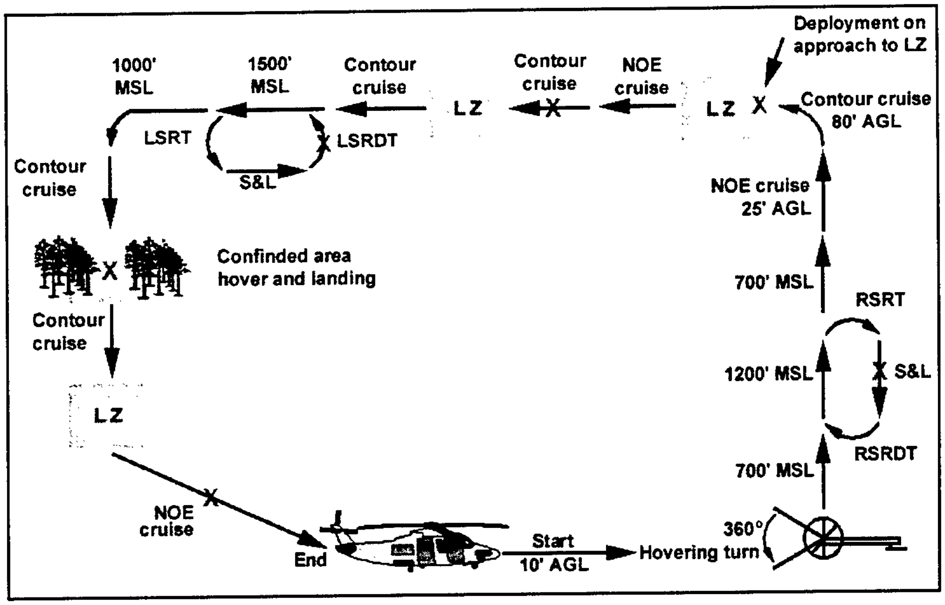


Figure 2. Mission flight profile. X's indicate maneuvers during which simulated inadvertent deployments were input into the sortie.

Data collection

Flight performance data were collected during the six maneuvers associated with simulated inadvertent deployments. When the simulator operator initiated the simulated airbag deployment, a marker was automatically placed in the flight performance data being collected. A second marker was placed in the data stream by the simulator operator when he determined the subject had returned to predeployment parameters.

To gauge the flight safety implications associated with each simulated deployment, the severity, as perceived by the test subject, simulator operator, and simulator observer, was recorded. Each event was rated on a scale of 0 percent (no effect on flight safety) to 100 percent (certainty of an accident). The subjects were asked to verbally rate the events immediately after regaining control of the aircraft (or crashing) and again, in written form, during a postflight debriefing. The simulator operator and simulator observer rated each simulated deployment in written form immediately after the subject regained control of the aircraft (or crashed).

Data analysis

The likelihood, or probability, of crashing as a result of a simulated deployment was determined. The outcome of each simulated inadvertent deployment, i.e., recovery or crash, was grouped according to the maneuver during which the event took place. For each maneuver, the percentage of simulated deployments that resulted in a crash was computed. The resulting percentage represented the likelihood of crashing if an inadvertent deployment was to occur during a specific maneuver.

Care was taken in determining which simulated deployments actually resulted in crashes. When the simulator software determines that a crash has occurred, it is signified by the forward and lateral viewscreens turning completely red. However, "red screens" are also triggered when an aviator exceeds safety limits on parameters such as engine torque. While potentially hazardous, exceeding these safety limits would not necessarily result in loss of the aircraft. For the purposes of this study, a red screen triggered by exceeding a safety limit was counted not as a crash, but as a recovery. Only impacts with the terrain or other obstacles were counted as crashes.

Video records were used to determine the time to recover from, or to crash as a result of, each simulated inadvertent deployment. Generally, this was taken as the time between the viewscreens turning white (the start of the simulated deployment) and either the subject safely recovering the aircraft from any erratic motions (resulting from the simulated deployment or their efforts to maintain control) or the aircraft impacting the terrain or an obstacle. For simulated deployments introduced during straight and level flight and left standard rate descending turns, the time to recover was the duration of time between the initiation of the simulated deployment and the subject regaining his predeployment flight parameters (e.g., airspeed, altitude, heading, rate of climb, etc).

Simulator timeout conditions

During some simulated inadvertent deployments, the modified flight simulator software used in this study caused the flight controls to malfunction (termed a "timeout" condition). Timeouts occurred when the flight controls were prohibited from maintaining their commanded positions (e.g., a 2-inch collective drop). During timeouts, the simulator software 'fought' subjects for control; this was caused by the simulator software trying to return the flight controls to their commanded positions as the subject input corrective flight control motions. Timeout conditions lasted the duration of simulated deployment (5 seconds). Afterward, the subject regained full control.

Timeouts made recovery more difficult. Therefore, crashes with timeouts were excluded from the analysis. However, if a subject managed to recover the aircraft despite a timeout, the data were retained in the analysis. In this study, 14 simulated deployments were influenced by timeouts. In 9 of the 14 cases, the subjects crashed, and the data were excluded from analysis.

Results

Originally, 10 subjects were recruited for this study. However, data sets from two subjects were unsuitable for analysis because of one subject's prior knowledge of the experimental methodology and another's inability to maintain flight parameters. A third subject's data were temporarily lost due to data acquisition problems. To replace these data sets, three additional subjects were recruited. While compiling data for analysis, the data set that was originally believed lost was successfully retrieved. Consequently, data from 11 subjects were considered in the analysis. These subjects had an average of 575 UH-60 Black Hawk flight-hours and 1680 hours total flight time.

Crash probability

Figure 3 shows the indicated airspeed and radar altitude at the instant of four-airbag CABS deployment. Also shown is probability of crash associated with each flight maneuver. Since S&L flight and the left standard rate descending turn (LSRDT) were performed at similar altitudes and airspeeds, a combined probability is presented.

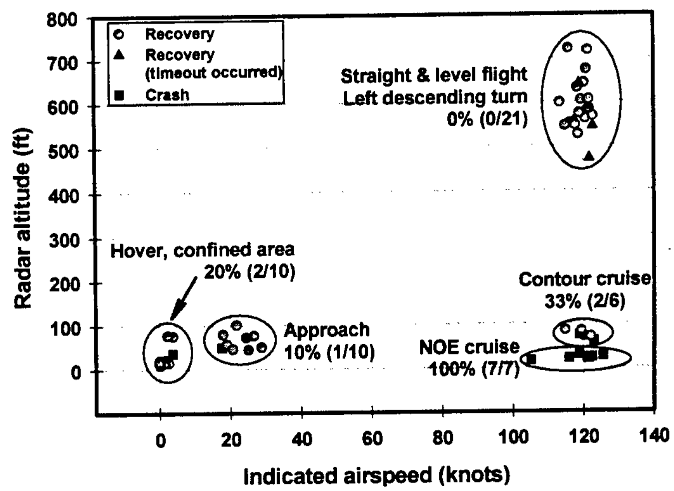


Figure 3. The probability of crashing associated with inadvertent deployments of a four-airbag CABS. Data shown include timeouts resulting in recovery.

Recovery time

The subjects typically took longer to recover from a simulated deployment than to crash (figure 4). Recovery times averaged 10.1, 10.2, and 6.4 seconds for the approach, contour, and confined area hover maneuvers, respectively. With the exception of one crash during the confined area hover, crashes occurred within 4 seconds or less of the onset of the inadvertent deployment. The only crash to take longer than 4 seconds occurred when a subject drifted into a tree while attempting to regain a stable 10-foot hover. This happened 17 seconds after the airbag deployment began.

Safety perceptions

The test subjects' perceptions of how severely the simulated deployments affected flight safety were grouped by maneuver (figure 5). The subjects' responses varied greatly for all maneuvers except NOE cruise. In their initial verbal ratings, the 7 subjects considered in the analysis (4 of the 11 subjects crashed as a result of timeout conditions) rated the severity of simulated deployments during NOE cruise flight at 100 percent (certainty of an accident). Postflight ratings remained high, at or above 85 percent.

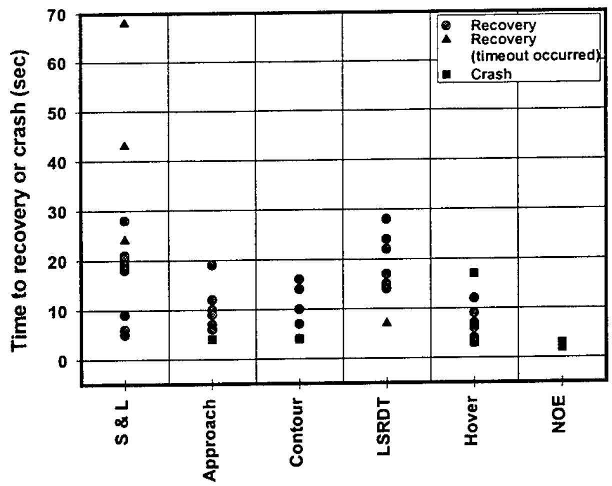
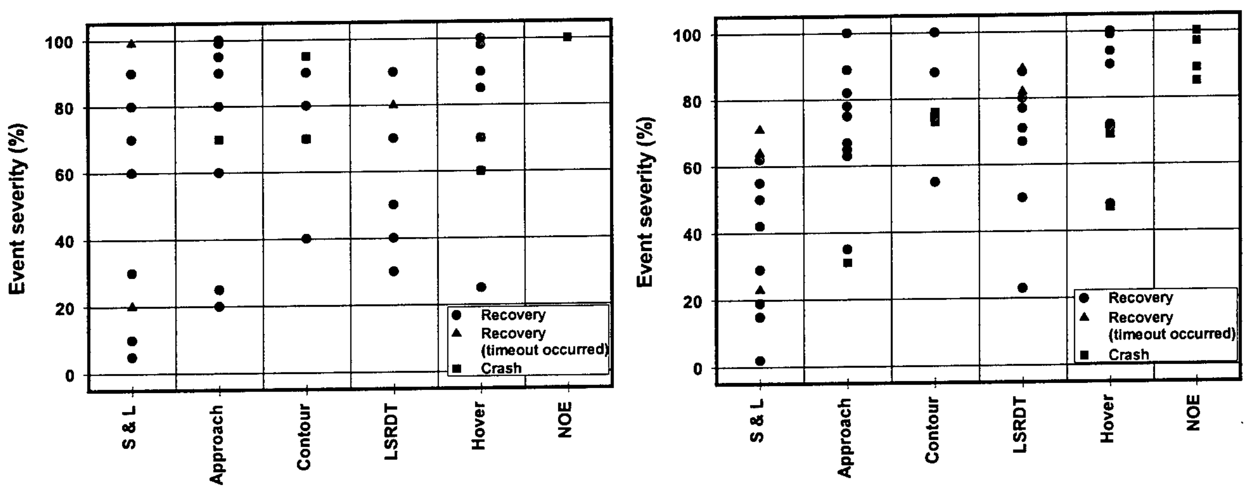


Figure 4. The time to recover (or crash) associated with inadvertent deployments of a four-airbag CABS. Data shown include timeouts resulting in recovery.

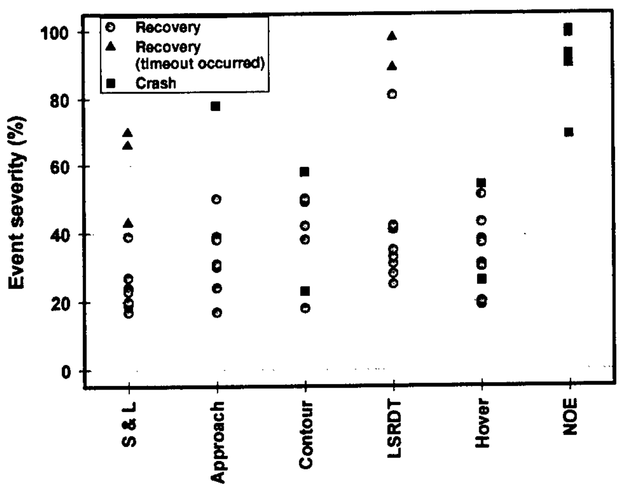


(a) In-flight

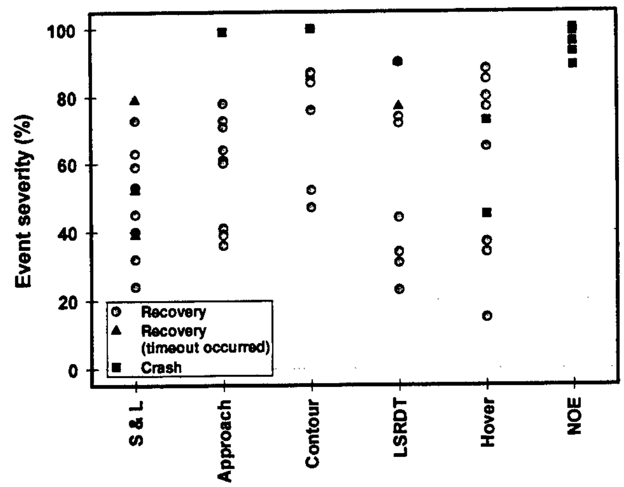
(b) Postflight

Figure 5. Event severity, as perceived by the test subjects, associated with inadvertent deployments of a four-airbag CABS. Data shown are the subjects' (a) verbal responses recorded immediately after regaining control of the aircraft or crashing and (b) written responses recorded during postflight debriefing. Data shown include timeouts resulting in recovery.

Figure 6 shows the severity of each simulated four-airbag CABS deployment as perceived by the simulator operator and simulator observer. As in figure 5, this figure shows variations in the perceived severity of each simulated deployment with the exception of those occurring during NOE cruise.



(a) Simulator operator



(b) Simulator observer

Figure 6. Event severity, as perceived by the simulator operator and observer, associated with inadvertent deployments of a four-airbag CABS. Data shown are responses recorded immediately after the test subjects regained control of the aircraft or crashed and include timeouts resulting in recovery.

Discussion

General

Inadvertent deployment of the four-airbag CABS appears to have little effect on flight control during maneuvers performed at high altitude. Almost every subject managed to recover from simulated deployments introduced during S&L flight and the LSRDT (figure 3). Each of these maneuvers was performed above 1000 feet (ft) above mean sea level (MSL). The higher altitude allowed subjects to sacrifice altitude while regaining aircraft control. Also, the high altitude removed the potential for striking obstacles (e.g., trees, telephone poles, etc.) while the visual displays were obstructed.

The probability of crashing when at low altitude shows a possible dependence on forward airspeed (figure 3). NOE cruise, contour cruise, hover, and approach maneuvers were all flown at or below 100 ft above ground level (AGL). NOE cruise and contour cruise maneuvers were flown at 120 knots indicated airspeed (KIAS) and were associated with the highest probabilities of crash of all maneuvers (100 percent and 33 percent). Hover and approach were performed at similar altitudes but lower airspeeds, between 0 and 30 KIAS. The probabilities of crashing corresponding to approach and hover were lower (10 percent and 20 percent). Further research would be required to determine more fully the nature of this relationship.

The results show a portion of the UH-60 flight regime in which an inadvertent deployment of the prototype four-airbag CABS would likely result in a crash. Height-velocity diagrams, similar to those already in use to show combinations of airspeed and altitude to avoid due to the risk of engine failure (Department of the Army, 1996), may have to be developed for CABS-equipped airframes. More research would be necessary to define more fully the critical altitude-velocity combinations.

Crashes appear to be most likely within the first few seconds following an inadvertent deployment (figure 4). Aviators who crashed did so within 4 seconds or less of the simulated deployments, with one exception – the subject who drifted into a tree while attempting to regain a stable 10-foot hover. Within these first few seconds, the subjects had to manage all aspects of the airbag deployment (e.g., uncommanded control motions, degraded views of the instrument panel and outside the aircraft), as well as the startling effect associated with the sudden introduction of these events into the sortie. Several subjects verbally expressed surprise when simulated deployments were initiated. Incorporating inadvertent deployments into aircrew training may provide a means of improving recovery time.

Study limitations

In some ways, the simulated inadvertent deployments used in this study may have been too severe. The flight control motions were a worst case condition in which the effects of inadvertent deployments on both the right crewstation (1-inch forward and 1-inch leftward cyclic motion) and left crewstation (2-inch drop in collective position) were inflicted on a single subject. The aviator's view out the windscreens may not actually be obstructed for a full 3 seconds, and the aircraft's forward and lateral windows may not be totally obstructed by the fully inflated airbags. It is also possible that some timeout conditions may have been caused by the fast reaction times of some subjects. These subjects may have reacted quickly enough to prohibit the flight controls from reaching or maintaining their commanded positions, thus introducing timeouts and possibly crashing as a result. For this reason, it is possible that some of the quickest subjects may have been unfairly penalized and excluded from the analysis.

However, in other aspects, the simulated inadvertent deployments may have been too mild. First, the effects of possible airbag-induced injury to the aircrew were ignored. Second, the subjects knew that the simulated deployments were going to occur. Third, the magnitude of the control motions may have been underestimated; during a concurrent live airbag deployment study using ATDs, the airbags were occasionally observed to impart cyclic displacements of at least four times those used in this study. Finally, few high power maneuvers (e.g., sling loads, mountain flying, etc.) were incorporated into the flight profile; maneuvers such as these would be more sensitive to the reduction in lift associated with the uncommanded collective displacement.

Study Two: Two-airbag CABS

During USAARL's aeromedical evaluation of the prototype four-airbag UH-60 CABS (simulated in Study One), a high probability of upper extremity injury was identified (McEntire, in press). These injuries were attributed to the prototype lateral airbags. At the request of the Program Manager, Aircrew Integrated Systems (PM-ACIS), this second study was conducted to assess the effect of inadvertent deployments of a two-airbag CABS (frontal airbags only, figure 1b) on aircraft control.

Method

The experimental apparatus, subject briefing, sortie, and data collection and analysis methods used in study one remained unchanged. Two modifications were made to the experimental method described previously.

First, the airbag simulation was modified to reflect the removal of the lateral airbags (table 2). As described earlier, the lateral airbags contributed to a 1-inch leftward motion of the cyclic and a 2-inch downward motion of the collective. These components were removed from the simulation. In addition, the removal of the lateral airbags also meant that the aviator's view out the lateral windows would no longer be blocked. Therefore, the lateral viewscreens remained unobstructed during the simulated deployment.

Table 2.
Components of simulated inadvertent deployment
of the two-airbag CABS.

Component	Event	Magnitude/duration
Cyclic motion	Forward	1 in.
Collective motion	None	N/A
Windscreen views	Forward display turns white	3 sec.
Instrument view	Panel lights black out	5 sec.
Deployment noise	Aural cue	--

Second, the number of subjects was increased to 11. In Study One, 7 of 7 subjects crashed as a result of the simulated deployment introduced during NOE cruise (figure 3). The principal comparison of interest to PM-ACIS was between this proportion (7/7) and the proportion of subjects crashing during deployment of the two-airbag CABS. Power calculations, using 7 subjects in Study One and 11 subjects in Study Two, and an alpha error of 0.05, yielded a power of 0.793 (SPSS Inc., 1999).

As in the four-airbag study, simulator timeout conditions occurred. Five simulated deployments were complicated by timeouts. In two of these cases, the subjects crashed and their data were excluded from analysis.

Results

Eleven subjects were planned for this study, but only 10 current and qualified UH-60 aviators could be recruited within the time allocated to complete the study. These 10 subjects had an average of 1551 UH-60 Black Hawk flight-hours and 2469 hours total flight time.

Crash probability

Figure 7 shows the altitude and airspeed at the onset of each simulated inadvertent deployment of the two-airbag CABS. The probability of crashing associated with each flight maneuver is also presented. Again, a combined probability of crashing is presented for S&L flight and the LSRDT.

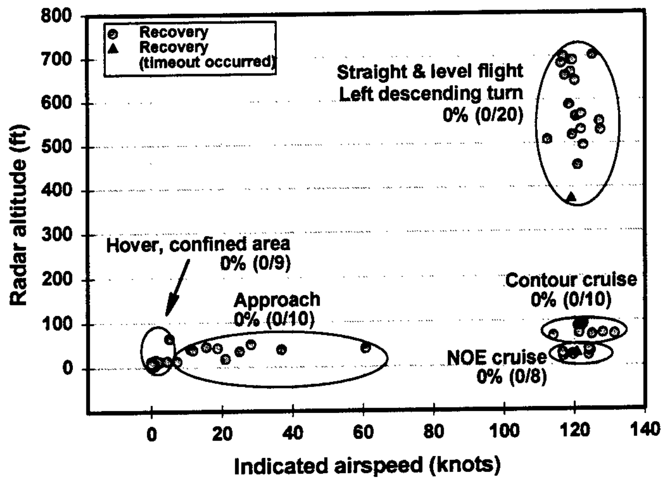


Figure 7. The probability of crashing associated with inadvertent deployments of a two-airbag CABS. Data shown include timeouts resulting in recovery.

Recovery time

The times to recover from the simulated two-airbag CABS deployments were grouped by maneuver and are presented in figure 8. The subjects averaged recovery times of 8.5, 6.1, 7.8, and 6.9 seconds for the approach, contour, hover, and NOE cruise maneuvers, respectively. Meanwhile, recovery times for the two instrument maneuvers – S&L flight and the LSRDT – were 15.6 and 19.9 seconds, respectively. After seven simulated deployments (two during S&L flight, three during contour cruise flight, and two during NOE cruise flight), the subjects recovered their aircraft in less time than it took to complete the airbag simulation (five seconds).

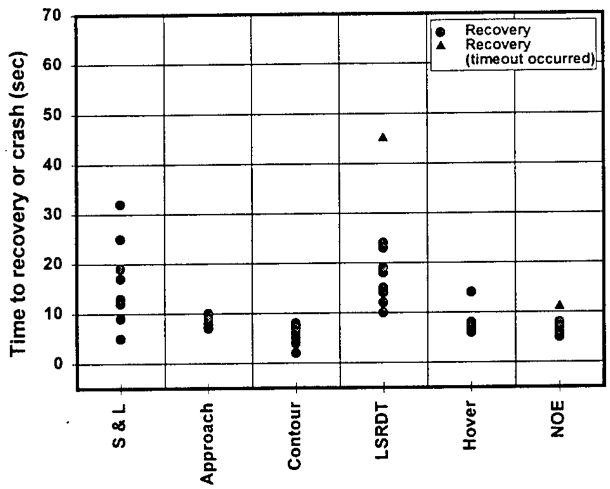


Figure 8. The time to recover (or crash) associated with inadvertent deployments of a two-airbag CABS. Data shown include timeouts resulting in recovery.

Safety perceptions

The severity of each simulated deployment of the two-airbag CABS, as perceived by the subjects, is shown in figure 9. As in the previous study, the subjects did not rate the severity of each simulated deployment consistently within the individual maneuvers.

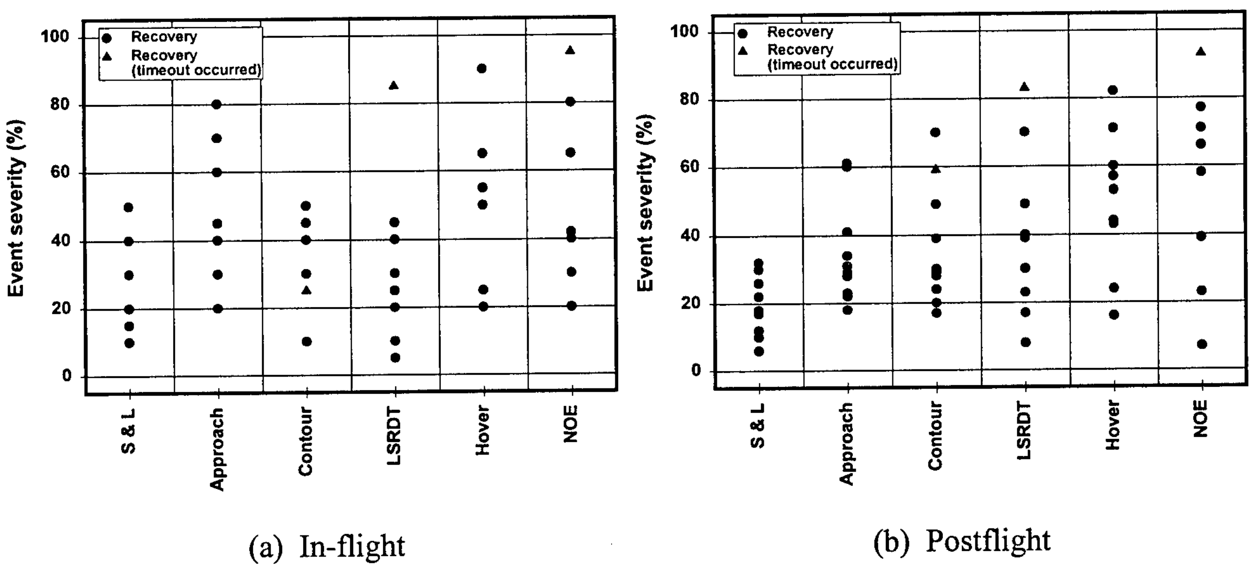
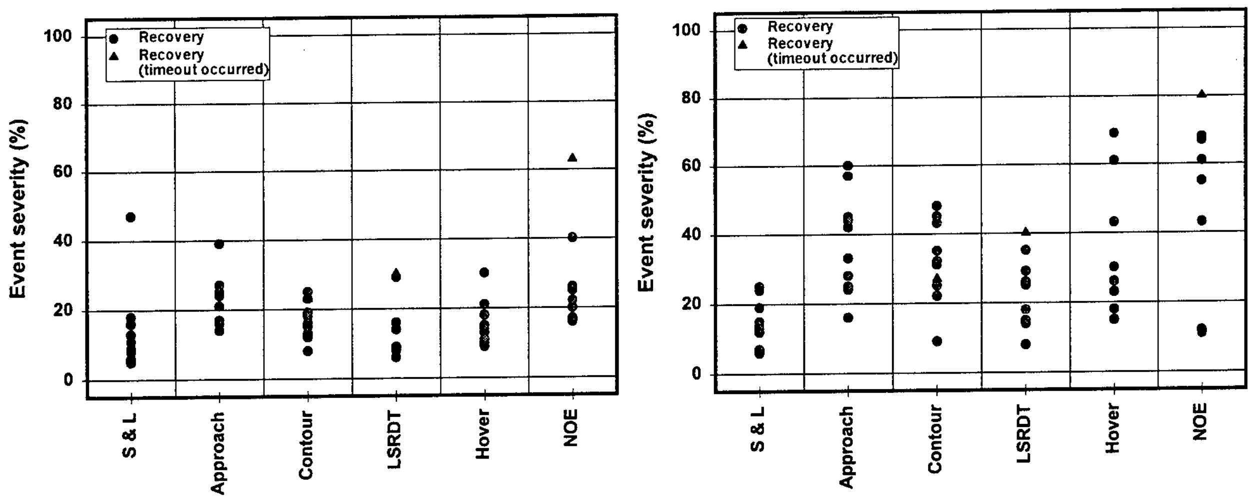


Figure 9. Event severity, as perceived by the test subjects, associated with inadvertent deployments of a two-airbag CABS. Data shown are the subjects' (a) verbal responses recorded immediately after regaining control of the aircraft or crashing and (b) written responses recorded during postflight debriefing. Data shown include timeouts resulting in recovery.

Figure 10 shows the severity of each simulated two-airbag CABS deployment as perceived by the simulator operator and simulator observer. The simulator operator consistently rated each simulated two-airbag deployment lower than did the subjects and the simulator observer. The simulator observer's ratings show a large variation but were similar in magnitude to the subjects' in-flight responses (figure 9a).



(a) Simulator operator

(b) Simulator observer

Figure 10. Event severity, as perceived by the simulator operator and observer, associated with inadvertent deployments of a two-airbag CABS. Data shown are responses recorded immediately after the test subjects regained control of the aircraft or crashed and include timeouts resulting in recovery.

Discussion

General

This investigation was conducted to examine the effects of simulated deployments of a two-airbag CABS on flight control. To assess these effects, this study examined the probability of crashing, time to recover, and perceived severity. Each of these metrics shows that inadvertent deployments of a two-airbag CABS had little detrimental effect on flight control.

The most obvious evidence of this fact can be seen in figure 7; no subjects crashed purely as a result of experiencing the deployments. One contributing factor to this lack of crashes may have been the unobstructed views out the left and right viewscreens. In 33 of the 57 deployments represented in figure 7, video analysis showed that the subjects immediately looked out either the left or right windows. By doing so, the subjects gained a visual reference on the aircraft's attitude and proximity to the terrain. Unrestricted collective motion may also have played a part in the absence of crashes. At the start of the simulated deployment, the subjects immediately pulled up on the collective, gaining altitude and removing the potential for impacting ground-based hazards (e.g., undulating terrain, trees, telephone poles, etc.).

The times to recover also show that these simulated deployments had little effect on flight control (figure 8). The strongest evidence of this are the seven deployments in which the subjects returned to stable flight before the simulated deployment ended. For the remaining deployments at low altitudes, the subjects regained controlled flight an average of 1.1 seconds (contour cruise flight), 1.9 seconds (NOE cruise flight), 2.8 seconds (confined area hover), and 3.5 seconds (approach) after the completion of the simulated deployment. These relatively short times to recover show that the subjects had little trouble regaining controlled flight after experiencing the simulated deployments.

Aviator experience may have had an effect on the lack of crashes and relatively rapid recovery times. The subjects participating in this study averaged 1551 UH-60 flight-hours – nearly three times the average UH-60 flight-hours of the subjects in Study One. More experienced aviators may have been more sensitive to changes in the cockpit environment (e.g., uncommanded flight control motions) and, therefore, able to react more quickly to the simulated airbag deployments. Also, the more experienced aviators may have been more proficient in basic emergency procedures, possibly helping them to recover the aircraft more quickly.

Study limitations

The simulated inadvertent deployments of the two-airbag CABS may have been more severe than an actual deployment. The forward airbags may not totally obstruct the aviator's view out the forward windscreen, and the aviator's view out the front windscreen may return in less than 3 seconds. As in the four-airbag CABS study, some timeout conditions may have been caused by the fast reaction times of some subjects, possibly resulting in the exclusion of some of the quickest subjects from the analysis.

However, in some ways, the simulated inadvertent deployments may have been too mild. As before, the effects of possible airbag-induced injury to the aircrew were ignored. Also, the subjects knew that the simulated deployments were going to occur. Finally, the control motions simulated in this study were far from worst case conditions. During live forward airbag deployments, the airbags were occasionally observed to impart cyclic displacements of at least four times those used in this study.

General discussion

These investigations were conducted to examine the flight control effects associated with the inadvertent deployment of a prototype four-airbag CABS (two forward and two lateral airbags) and a two-airbag CABS (two forward airbags). Comparing the results of these studies shows that aviators had a more difficult time maintaining aircraft control after an inadvertent deployment of the prototype four-airbag CABS. All measures of flight controllability (probability of crashing, time to recover, and perceived severity) were more adversely affected by simulated four-airbag CABS deployments.

When simulated inadvertent deployments of the prototype four-airbag CABS were introduced during low altitude maneuvers, the likelihood of crashing increased significantly. In the two-airbag study, the probabilities of crashing were 0 percent for all low altitude maneuvers (figure 7). However, for the four-airbag study, probabilities of crashing when at low altitude ranged from 10 (contour cruise flight) to 100 percent (NOE cruise flight) (figure 3). No comparisons can be made for high altitude maneuvers, as no subjects crashed during either study.

PM-ACIS was concerned primarily with the effect that inadvertent deployment of the two-airbag CABS would have on the probability of crashing during NOE cruise flight. A z-test showed a significant difference ($p < 0.001$) in the proportion of subjects that crashed as a result of the four-airbag CABS deployments during NOE cruise (7 of 7) and the proportion of subjects who crashed after a simulated two-airbag CABS deployment (0 of 10).

As with the probabilities of crashing, recovery times were adversely affected by the simulated inadvertent deployments of the prototype four-airbag CABS. For most maneuvers, the subjects participating in the four-airbag study took longer to recover from the simulated inadvertent deployments. However, the subjects participating in the two-airbag study took longer to recover from deployments during the LSRDT and the confined area hover. During the four-airbag study, 3 of the 10 subjects regained control by successfully performing intentional landings. This method of recovery was faster than attempting to gain altitude and return to stable flight, as the 10 participants in the two-airbag study did. The faster recovery times had the effect of lowering the average recovery time. No subjects managed to recover from simulated four-airbag deployments introduced during the NOE cruise maneuver; that in itself is also evidence of the adverse effect of the prototype four-airbag CABS on flight control. Also, the longer recovery times indicated that the subjects had more difficulty recovering from the simulated deployments involving lateral airbags.

The subjects believed that deployments of the four-airbag CABS had a greater effect on flight control than the two-airbag CABS deployments. Forty of 54 in-flight responses shown in figure 5a were above 50 percent, showing that the subjects believed the four-airbag CABS posed a better than even chance of causing an accident. With regards to the two-airbag CABS deployments, 14 of 57 responses were above 50 percent (figure 9a). As shown previously, the subjects participating in the four-airbag CABS study experienced more crashes and had more difficulty in regaining flight control than their counterparts in the two-airbag CABS study. These factors may explain the differences in perceived severity. Similar trends can be seen in the subjects' postflight responses (figures 5b and 9b), as well as in the responses of both the simulator operator (figures 6a and 10a) and observer (figures 6b and 10b).

The possibility exists that the subjects from both studies became conditioned to the simulated airbag deployments. Each subject was exposed to six simulated deployments during their 1-hour sortie. After successive deployments, the subjects may have become more proficient in managing the effects of the simulated deployments. However, these studies were not designed to identify or assess any conditioning that may have occurred during the sorties. Therefore, while conditioning may have influenced the results of these studies, the extent of that influence, if any, could not be determined.

As mentioned earlier, aircrew training may help to mitigate the detrimental effects of inadvertent deployment on flight control. During training, aviators could be repeatedly exposed to simulated CABS deployments, as they are to other aircraft emergencies. Through repeated exposures, aviators would learn what to expect during an inadvertent deployment (e.g., uncommanded flight control motions, temporary obstruction of the aviator's view out the windows, etc.), possibly reducing any startling effect. As with other aircraft emergencies, repetition would also reinforce emergency procedures. This may help to minimize recovery times and crash probabilities.

The simulated airbag deployments used in these studies were modeled after a specific prototype UH-60 CABS. These studies showed that inadvertent deployment of this particular prototype four-airbag CABS was a threat to flight control during low altitude, high speed maneuvers; however, the assumption should not be made that all four-airbag systems will present the same risk. Also, four-airbag systems provide greater protection than two-airbag systems due to the presence of the lateral airbags. Lateral airbags provide increased protection against flail-induced injuries.

References

Alem, N.M., Shanahan, D.F., Barson, J.V., and Muzzy, W.H. 1992. The effectiveness of airbags in reducing the severity of head injury from gunsight strikes in attack helicopters. Neuilly-sur-Seine, France: AGARD Conference Proceedings 532.

Brozoski, F.T., Crowley, J.S., McEntire, B.J., Johnson, P.A., Cruz, V.J., and Dalgard, C.L. In press. The UH-60 cockpit airbag system: A preliminary anthropometric analysis. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Technical Report (report number to be assigned).

Crowley, J.S. 1991. Should helicopter frequent flyers wear head protection? Journal of Occupational Medicine. 33:766-769.

Department of the Army. 1996. Operator's manual for UH-60A helicopter, UH-60L helicopter, EH-60A helicopter. Technical Manual, TM 1-1520-237-10.

McEntire, B.J. In press. Predicting airbag-related injury using anthropometric test devices. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Technical Report (report number to be assigned).

Raytheon Systems Company. 1999. USAARL airbag study modifications to 2B38/UH-60 SFTS: Configuration, operation, and limitations. Contractor-supplied documentation.

Shanahan, D.F. and Shanahan, M.O. 1989. Injury in U.S. Army helicopter crashes: October 1979 through September 1985," Journal of Trauma. Vol 29.

Shanahan, D.F., Shannon, S.G., and Bruckart, J.E. 1993. Projected effectiveness of airbag supplemental restraint systems in U.S. Army helicopter cockpits. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report 93-31.

SPSS, Inc. 1999. Sigmastat statistical software. Version 2.0. Chicago, Ill: SPSS, Inc.

Appendix.

Detailed flight profile.

Item	Description	Time (min)	Heading (deg)	Altitude (feet)	Airspeed (KIAS)	Airbag event	Comments
1	Hover	1	090	10'AGL	0		
2	Left hovering turn	1	090>090	10'AGL	0		
3	LL CP 11 - 12	4	086	700'MSL	120		
4	CLIMB @ 500 fpm	1	100	700>1200' MSL	120		
5	RSRT	1	100>280	1200' MSL	120		
6	S&L	1	280	1200 MSL	120	1	
7	RSRT/DESC	1	280>100	1200>700 MSL	120		
8	CP 12 – 13	1	100	700 MSL	120		
9	NOE CP 14 – 15	3	344	25' AGL	120		
10	CONT CP	3	031	80' AGL	120		
11	LAND FARP 1	2	015	0	0	2	On approach
12	NOE CP 16 – 17	4	338	25'AGL	120		
13	CONT CP 17 – 18	2	296	80' AGL	120	3	Contour 50'
14	LAND FARP 36	2	255	0	0		
15	CONT CP 18 – 19	4	319	80' AGL	120		
16	CONT CP 19 – 20	2	250	80' AGL	120		
17	CLIMB @ 500fpm	1	200	1000>1500 MSL	120		
18	LSRT	1	200>020	1500 MSL	120		
19	S&L	1	020	1500 MSL	120		
20	LSRT/DESC	1	020>200	1500>1000 MSL	120	4	Left descending turn
21	CONT CP 21 – 22	3	173	80' AGL	120		
22	LAND CLA #3	2	215	0	0	5	Hover, confined area
23	CONT CP 22 – 23	4	066	80' AGL	120		
24	CONT CP 23 – 24	2	076	80' AGL	120		
25	CONT CP 24 – 25	2	181	80' AGL	120		
26	CONT CP 25 – 46	4	214	80' AGL	120		
27	LAND MLA #3	2	180	0	0		
28	NOE CP 26 – 11	4	249	25' AGL	120	6	NOE

KIAS = Knots indicated airspeed
MSL = Mean sea level
AGL = Above ground level
R(L)SRT = Right (Left) standard rate turn
S&L = Straight and level
NOE = Nap of the earth

CONT = Contour
LL = Low level
CP = Check point
FARP = Forward arming and refueling point
DESC = Descending